NATIONAL BUREAU OF STANDARDS REPORT

7498

COLOR VISION TESTER FOR AIR PILOTS

by

F. C. Breckenridge

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Report to

Aviation Research and Development Service
Federal Aviation Agency

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Color-Vision Tester for Air Pilots

Prepared for

Federal Aviation Agency

Preliminary Conferences.

As requested by the Aviation Research and Development Service of the Federal Aviation Agency a study has been made of the requirements for a color-vision tester to determine if candidates for air-pilot licenses meet the legal requirements as to ability to recognize the colors of signal lights which conform to the requirements for aviation red, aviation white, and aviation green. The problem was discussed in two conferences by Mr. Walter C. Fisher, Project Manager for the project, and Messrs. D. B. Judd and F. C. Breckenridge of this bureau. It was agreed that the tester should be a practical device limited to exposing signals of the above colors. This was considered advisable both for legal reasons and for the purpose of avoiding unnecessary complaints from candidates who might be rejected and think that the rejection was occasioned by the peculiarities of the test.

In view of the above the first problem was to determine the general design for the test. As a basis for planning, it was agreed that we should use the recommendations in the report on the Navy New London lantern prepared by Comdr. Dean Farnsworth*, but that the design of the tester and the procedure should be modified as required to make the test a practical test of color recognition rather than a test for color blindness. Thus the viewing distance of 8 feet, which was selected to make it feasible to carry out the test in an ordinary office, should be retained, but the procedure of showing two lights at each exposure was considered to be both unnecessary and undesirable for this purpose since its use had been based upon an attempt to deceive the color defective subject; pilot applicants might consider it an unrealistic test because in most cases the recognition of aviation lights depends upon the appraisal of an individual light. In Farnsworth's discussion of the principles underlying lantern tests, he states that they "make use of certain 'tricks' or artifices", and in his introductory formula he avoided disclosing to his subjects that the two lights shown together might be of the same color or that the same colors would appear in different brilliances. This sort of "trick" should be unnecessary if the lights are shown singly with enough different intensities for each so that it is not likely that the candidate will make any correlation between intensities and chromaticities. To assure this, however, the use of at least three intensities for each color seems desirable.

The next problem was the selection of the aviation red, aviation green, and aviation white chromaticities which would be most likely to be confused out of all the chromaticities which conform to the definitions for these colors. It was at once evident that we need concern ourselves only with those abnormalities of color vision that cause the confusion of these red, white, and green lights. It was agreed in the conferences referenced above

*Color Vision Report No. 12, N.L. Sub-1-CV-15, BuMed X-457 (Av-241-k), 1946.

that the chromaticities conforming best to this requirement are: (1) a pale limit red; (2) a green which would be represented by a point in the pale yellow corner of the acceptable green area on the chromaticity diagram; and (3) a white represented by that point on the Planckian locus which is in line with the red and green selected. These three collinear points do not lie exactly on a chromaticity confusion locus for either of the two types of red-green confusers, but they approximate such a locus as well as is possible with pale-limit red and green signals. Both experience and color recognition tests indicate that the pale-limit chromaticities are most often confused.

Development of Requirements.

The relationship of the chromaticities selected to the basic chromaticity definitions as given in Part I of the Tentative U.S. Standard for the Colors of Signal Lights is shown in Figure 1 in RUCS coordinates. A simple calculation shows that the point on the Planckian locus which also lies in the line joining the selected red and green has a color temperature of approximately 2355°K. The simplest way to obtain the desired green chromaticity, however, is to use a duplicate of tentative national standard filter 7.134 with a source having a color temperature slightly above 1904°K. Filters are readily available for changing the chromaticity of a source at 1904°K to match that of a source of color temperature 2355°K. To obtain a suitable red with a source at 1904°K it is only necessary to select a filter just enough yellower than is normally used for pale-limit aviation or signal red with the standard 2854°K source to compensate for the difference in source. A lamp operated to give a color temperature of, or slightly above, 1904°K is accordingly recommended.

As a basis for estimating a suitable range of intensities for the signals, we have assumed that the difficulty of recognition should be comparable to that of recognizing the signals of a portable traffic control projector under relatively difficult but normal service conditions. Two cases appear typical of these conditions: a pilot in flight three miles (15000 feet) from the control tower seeing the signals against the terrain in a direction away from the sun; and a pilot on the end of a runway one mile (5000 feet) from the control tower seeing the signals against a bright sky but not sufficiently in line with the sun to constitute a glare problem. In Table I these conditions are compared with three conditions included in the report on the New London lantern.

This table consists of three sections descriptive of the source, background, and signal respectively. Since the known characteristics are not the same in the different cases, the known and assumed values have been underscored to distinguish them from the computed values. If one were to estimate the difficulty of color recognition from either the source luminance or the signal illuminance, the recognition of the traffic-control signal projector colors would appear much less difficult than the recognition of the colors of the lantern. This estimate, however, would leave out of account the difference in background luminance. The final column of the table which gives the ratio of signal luminance to background luminance

indicates that the recognition of the traffic-control projector colors under the assumed service conditions should be somewhat more difficult than was the recognition of the colors of the New London lantern even under a condition which caused some "normal" observers to make some errors. This presents a dilemma for we must assume either that some of the observers on the lantern test, notwithstanding that they had been screened with pseudo-isochromatic plates and the Dimmick anomaloscope, would not be able to identify signal colors satisfactorily, or that the service conditions we have selected are too severe to serve as a test. Since the capabilities tested by the pseudo-chromatic plates and the anomaloscope are somewhat different from those required for the identification of colors in point sources, and the screening tests did not require perfect scores, it seems most reasonable at this stage to assume that these tests do not constitute a satisfactory basis for distinguishing between those who are able to recognize the aviation signal colors and those who can not do so.

Table II contains recommendations for designing and using the proposed color-vision tester for pilots. The test distance is the same as that used for the New London lantern, but the recommendations call for three sizes of apertures instead of only one. The largest aperture is the same size as is used in the New London lantern. The smallest one subtends just over 1 minute at the observation distance of 8 feet so that it is virtually a "point" source. The diameter of the middle one is approximately the geometric mean of the other two. The recommendations also call for three values of signal luminance. The brightest signals are to be of the lower luminance recommended in the report for the New London lantern, and the dimmest has been selected to make the signal ratio just slightly larger than that computed for the traffic control projector as seen at three miles by a pilot in flight. The intermediate luminance is approximately the geometric mean of the other two. Since the aperture area and luminance also control the signal ratio and the illuminance at the observer's eye, these quantities also approximate geometric ratios and the signals should appear to the observer to be related by equal steps of brilliance.

Tolerances.

For the procurement of a large number of color-vision testers it is necessary to have specific tolerances for the chromaticity and the luminance of the signals. These tolerances must be reasonably small in fairness to the candidates as otherwise the acceptance or rejection of a candidate will depend on the characteristics of the particular tester with which he is tested. This rules out the use of the broad specifications which are the basis for the procurement of signal ware. The tolerances recommended for the control of duplicates of the pale limit standard filters, on the other hand, would make the tester unnecessarily expensive.

The cost of quality control per unit diminishes as the quantity to be controlled increases. We have been informed that approximately 5000 of the testers will be needed, and on this basis we are assuming that tolerances about twice those recommended for the duplication of standard filters will be practicable. A further support for tolerances of this magnitude is found

in the fact that all these filters will have flat polished, or uniformly depolished surfaces, which facilitates a close control of thickness, and that the filters can be cut from plates or rods which have already been subjected to quality control. Both glass and plastic should be considered as suitable materials for the filters and there is no necessity that filters for all the colors be made from the same kind of material.

The tolerances recommended for the three filters which will be required for each tester are stated in Table III and shown diagrammatically in Figures 2 to 7. These tolerances are applicable with a source of color temperature 1904°K. Since the testers are always to be used with the lamp at this color temperature, and the variation in chromaticity allowed is relatively small as compared with that which must be allowed for ordinary signal ware, it is not necessary that the material used for the filters have "chromaticity characteristics" similar to those of the standard filters provided the chromaticities are within the tolerances. To meet the requirements for signal luminance given in Table II within a reasonable tolerance of, let us say, ±15%, it will probably be necessary to use neutral filters for all three cases. The transmittance values required for these filters will depend upon the characteristics of the lamp selected and the transmittance of the red, green, and lunar filters. The neutral filters should not distort the chromaticities so much as to cause the resultant colors to fall outside of the tolerances of Table III.

Voltage Stabilization.

Since variations in voltage will cause variations in both the luminance and the chromaticity of the signals, and considerable variations in the service voltages supplied the testers are inevitable, it is recommended that the tester contain some sort of voltage stabilizer. To determine how closely the voltage should be controlled, it is first necessary to fix a maximum limit for the chromaticity variations that are acceptable. These should be small in comparison with the tolerances allowed for the filters and the following values have been used to determine the maximum acceptable voltage variations for a 100-watt, 110-volt projection lamp operated to give a color temperature of 1904°K:

$$\text{Red},\ \Delta y'' = \pm 0.0005;\ \text{White},\ y'' = \pm 0.0005;\ \text{Green},\ \Delta x'' = \pm 0.0002$$

From these values corresponding limits for variation in filament color temperature have been determined, and from these in turn, limits for the allowable voltage variation have been computed with the following results:

Allowable voltage variations in percent.

Red	White	Green
$\Delta V/V = +3.1\%$	$\Delta V/V = +0.7\%$	$\Delta V/V = +0.8\%$
$\Delta V/V = -2.5\%$	$\Delta V/V = -0.6\%$	$\Delta V/V = -0.9\%$

For a color temperature of 1904°K, a 110-volt, 100-watt projection lamp will require somewhat less than 35 volts and 20 watts. These values suggest a transformer similar to those commonly used for operating the filaments of electronic equipment. These transformers are commonly designed to hold the voltage within ±1%, but since in this application they will all have the same load, the same frequency, and approximately the same ambient temperature, it seems probable that such transformers can be designed to meet the above requirements without making them prohibitedly expensive.

Mechanical Design.

The tester should be designed so that the nine exhibits, three colors each at three intensities, can be shown in any order. This may be done by passing over filters but there must be no sound or flashes from the signals being passed over which could give the subject a cue as to the proper answer. The operator should be able to tell at a glance which exhibit is being shown. It may be convenient to have the design such that the tester can be operated from either the back or the side without the operator getting a false indication of the exhibit being shown. It does not seem advisable, as recommended for the New London lantern, to open the lamp circuit between exhibits as such a procedure wastes time and runs the risk that a signal will be shown before the lamp has come to its calibration temperature. On the other hand, the lamp will be operating at such a low color temperature it may be expected to furnish many years of satisfactory service.

The New London lantern was designed so that the filters were mounted on the vertical surface of a nine sided prism. Such a design should be satisfactory, as would also be a cylinder with its axis vertical. Another promising approach to a design that could be easily operated would be to place all the filters in a vertical disc mounted with its axis parallel to the line of sight. It is suggested that the specifications should be broad enough to make any of these and other approaches acceptable in order to get the lowest cost consistent with the reliable reproduction of the chromaticities and luminances which are essential to a standardized test.

Table I. Comparison of observation conditions for the New London lantern tests with those of air pilots.

Case	Source Distance (feet)	Source Diameter (inches)	Source Angle (minutes)	Source Luminance (ft.Lamb)	Source Intensity (candles)	Background Illuminance (ft.cand)	Background Reflectance (ratio)	Background Luminance (ft.Lamb)	Signal Illuminance (ft.cand)	Ratio L_s/L_b
Lantern higher lum.	8.	0.08	2.86	80.	0.00089	6.	0.2	1.2	$14.\times10^{-6}$	67.
Lantern lower lum.	8.	0.08	2.86	32.*	0.00036	6.	0.2	1.2	$6.\times10^{-6}$	27.
Lantern small aper.#	8.	0.02	0.72	40.	0.000028	6.	0.2	1.2	$.4\times10^{-6}$	17.3##
Pilot on runway	5000.	8.0	0.46	68000.##	36000.	sky	---	5000.	$1400.\times10^{-6}$	13.7
Pilot in air	15000.	8.0	0.15	3800.##	18000.**	8000.	0.1	800.	$80.\times10^{-6}$	4.72

* Value recommended in New London report. Tests were made with a luminance of 40. footLamberts as shown in next line.

\# On this test some normals made some errors.

\## Based on an area subtending an angle of 1 minute which covers the minimum perceptive area of the retina. On this basis the effective luminance of the New London lantern with the aperture 0.02 inches in diameter would be 21 footLamberts.

** Reduced to allow for 0.5° inaccuracy of aim.

Underscored values are taken from the New London report or assumed upon the basis of available information. All other values are computed from these.

Table II. Proposed conditions of signal observation.

Case	Distance (feet)	Diameter (inches)	Angle (minutes)	Signal Luminance (ft.Lamb)	Background Luminance (ft.Lamb)	Ratio, Signal to Background	Signal Illuminance (ft.cand)
I	8	0.08 (2.0 mm)	2.86	32.0	1.2	26.7	5.4×10^{-6}
II	8	0.05 (1.3 mm)	1.79	14.0	1.2	11.7	0.9×10^{-6}
III	8	0.03 (0.8 mm)	1.07	6.0	1.2	5.0	0.15×10^{-6}

Table III. Tolerances for F.A.A. Color Vision Tester.

Source color temperature 1904°K

$\Delta x = x - x_0$, $\Delta y = y - y_0$

x_0 and y_0 are coordinates for reference filter.

RED FILTER

Reference filter, NBS 3656*

Filter NBS 3656, $x_0 = 0.6745$, $y_0 = 0.3253$	
Saturation boundary,	$\Delta y = +0.0055$
Yellow boundary,	$\Delta y = +0.0085$
Purple boundary,	$x + y = +0.9990$

*Present pale limit standard for Aviation Red. At 1900°K standard does not give chromaticity within tolerances, both tolerances are positive.

GREEN FILTER

Reference filter, AAR 134#

Filter NBS 7.134, $x_0 = 0.3197$, $y_0 = 0.4944$	
Saturation boundary,	$\Delta y = +0.0010 + 0.25\Delta x$
White boundary,	$\Delta y = -0.0010 + 0.25\Delta x$
Yellow boundary,	$\Delta x = +0.0001$
Blue boundary,	$\Delta x = -0.0030$

#This filter becomes National Standard Filter 7.134 under Tentative U.S. Standard for Colors of Signal Lights.

"WHITE" FILTER *

Reference filter, NBS 8481

Filter NBS 8481, $x_0 = 0.488$, $y_0 = 0.4122$	
Yellow boundary,	$\Delta x = +0.0050$
Blue boundary,	$\Delta x = -0.0020$
Green boundary,	$\Delta y = +0.0030 + 0.08\Delta x$
Purple boundary,	$\Delta y = -0.0005 + 0.08\Delta x$

*The filters required to obtain the white signal will have transmittance characteristics similar to those commonly used to raise the apparent color temperature of a light source. These filters appear bluish when viewed against a white background.

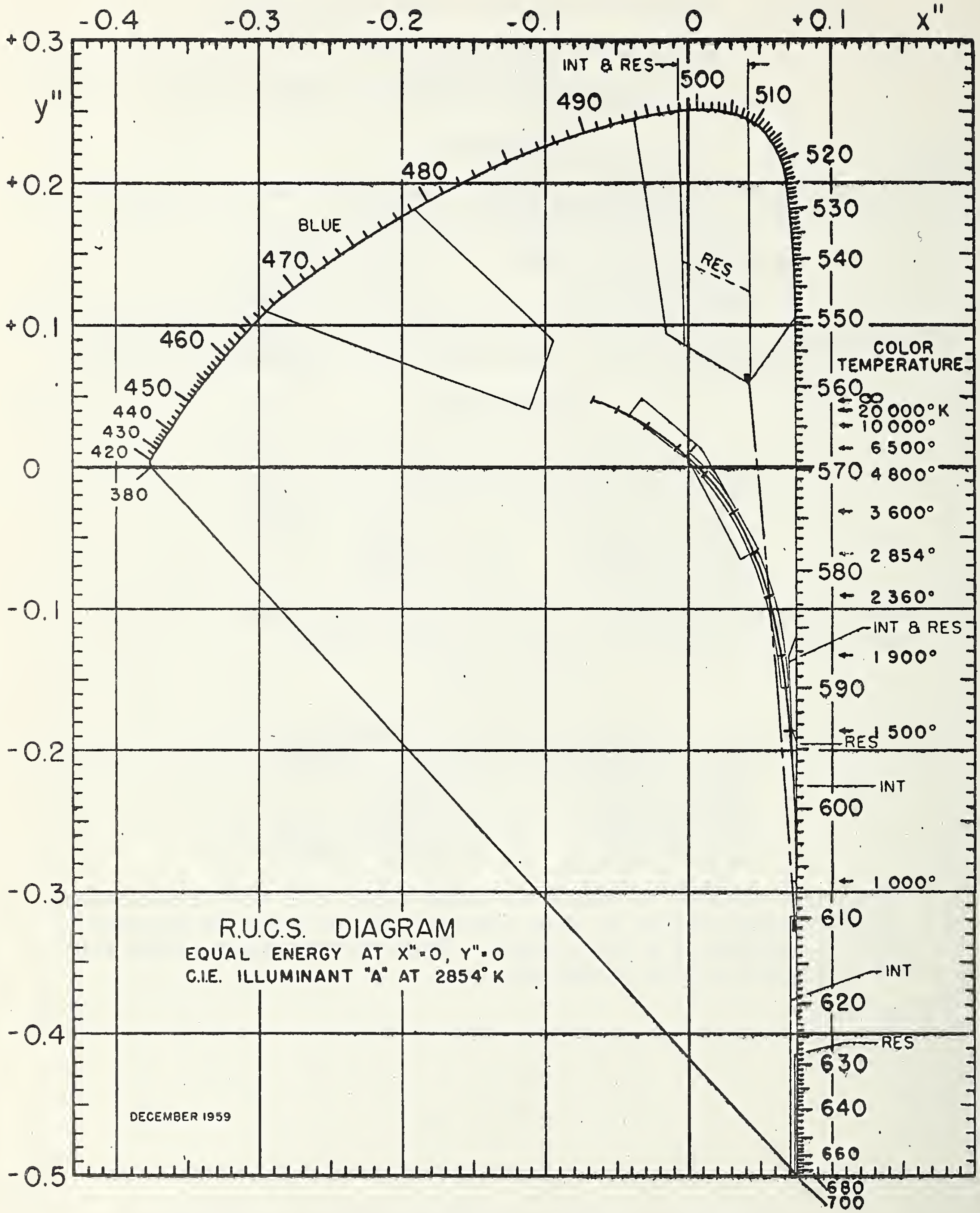

Figure 1. U.S. STANDARD SIGNAL COLORS showing relative locations of three colors recommended for vision tests.

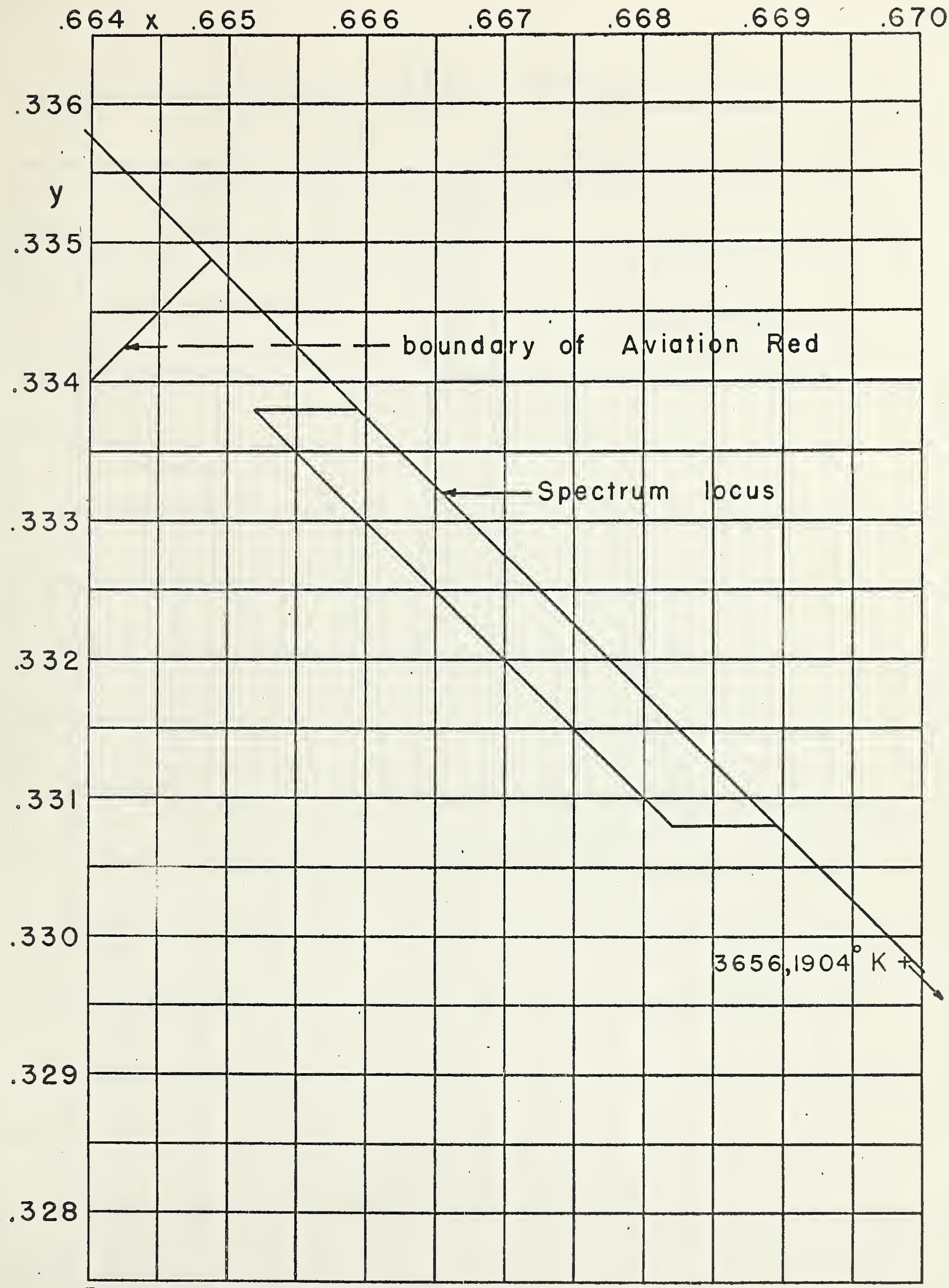

Figure 2. Tolerances for Red Filters. C.I.E. chromaticity diagram showing tolerances proposed in Table III for the red filters. (Reference filter falls outside of diagram).

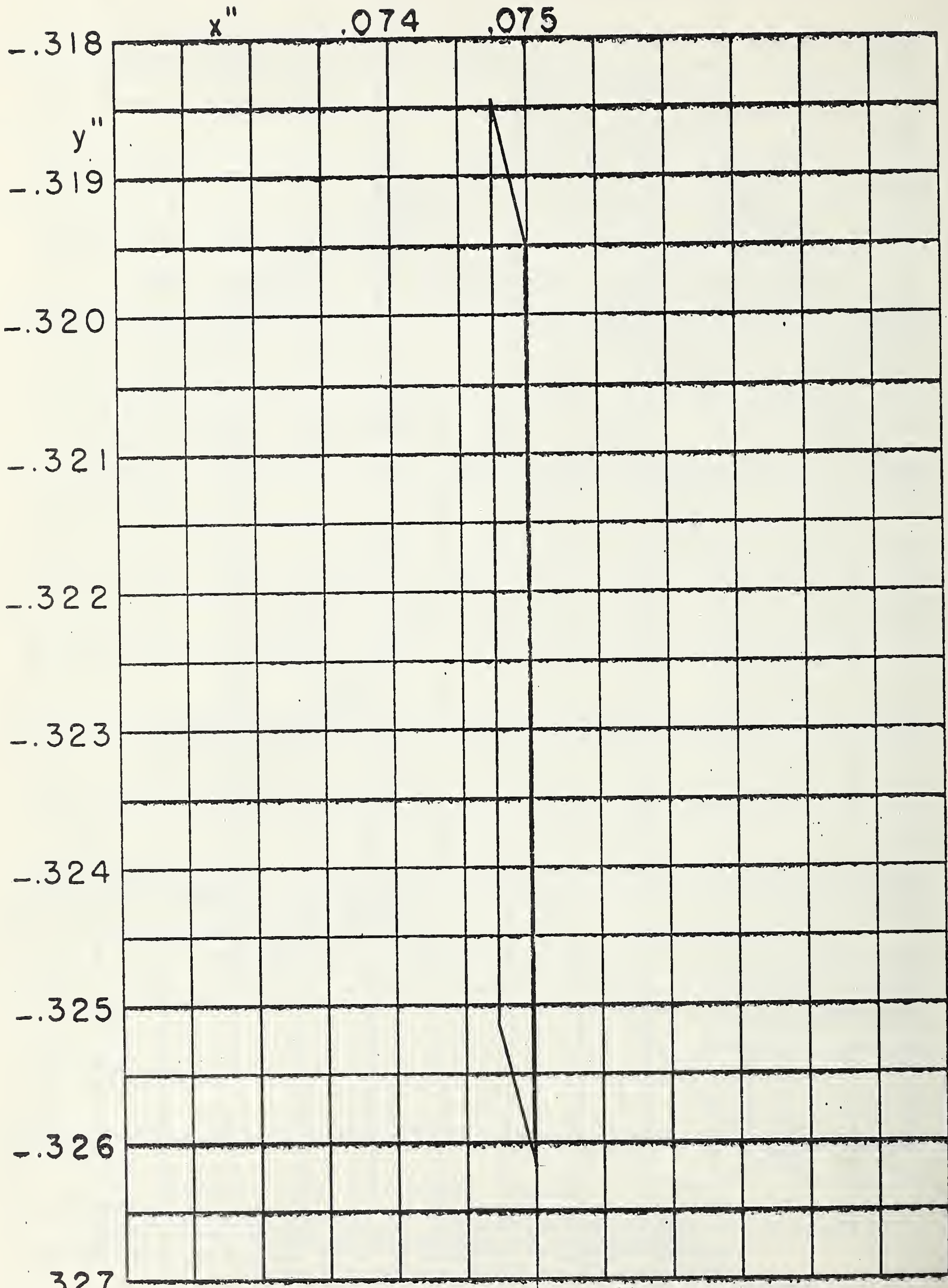

Figure 3. Tolerances for Red Filters. RUCS transformation of Figure 2 in more nearly uniformly-spaced chromaticities.

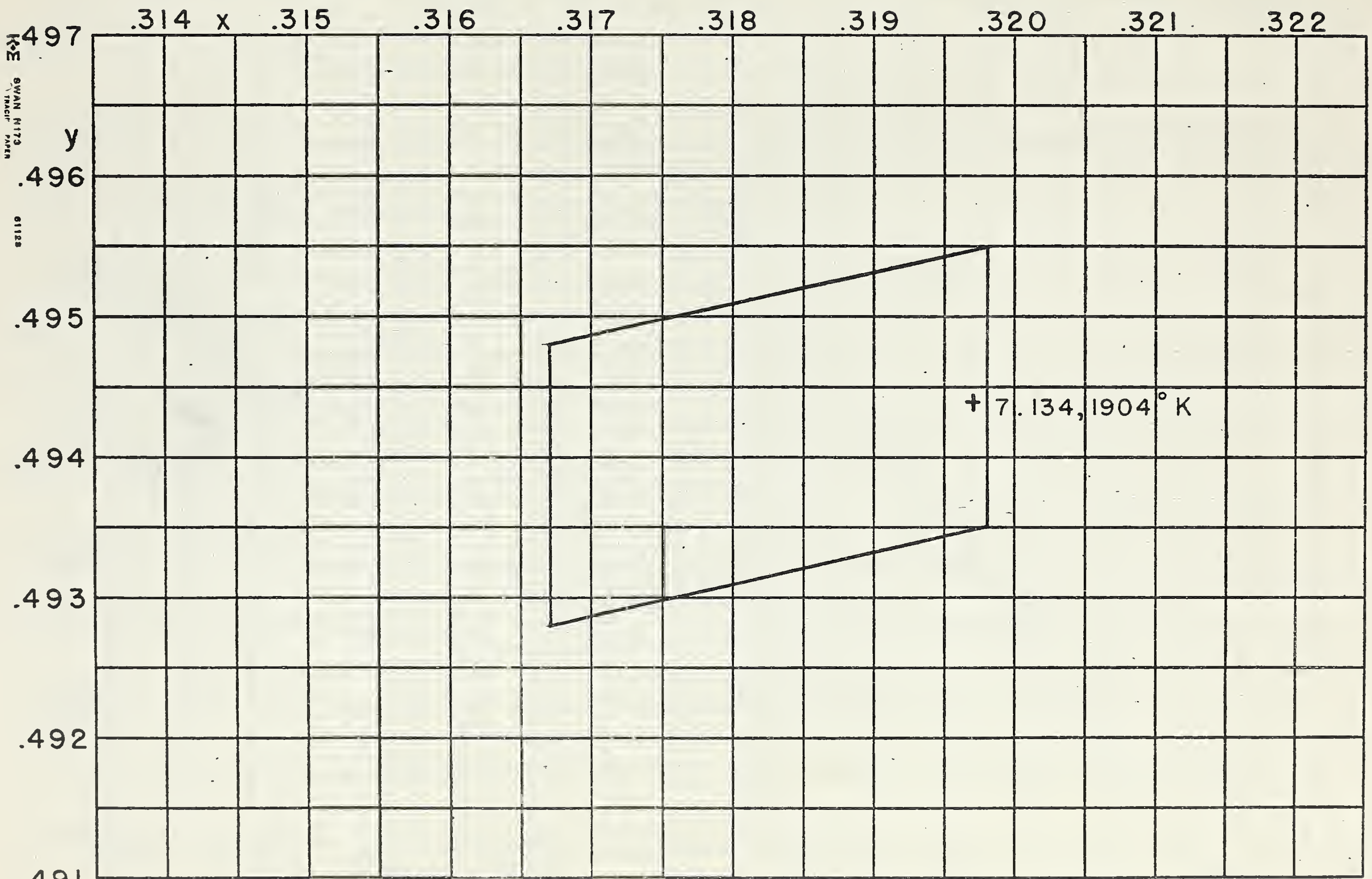

Figure 4. Tolerances for Green Filters. C.I.E. chromaticity diagram showing tolerances proposed in Table III for green filters.

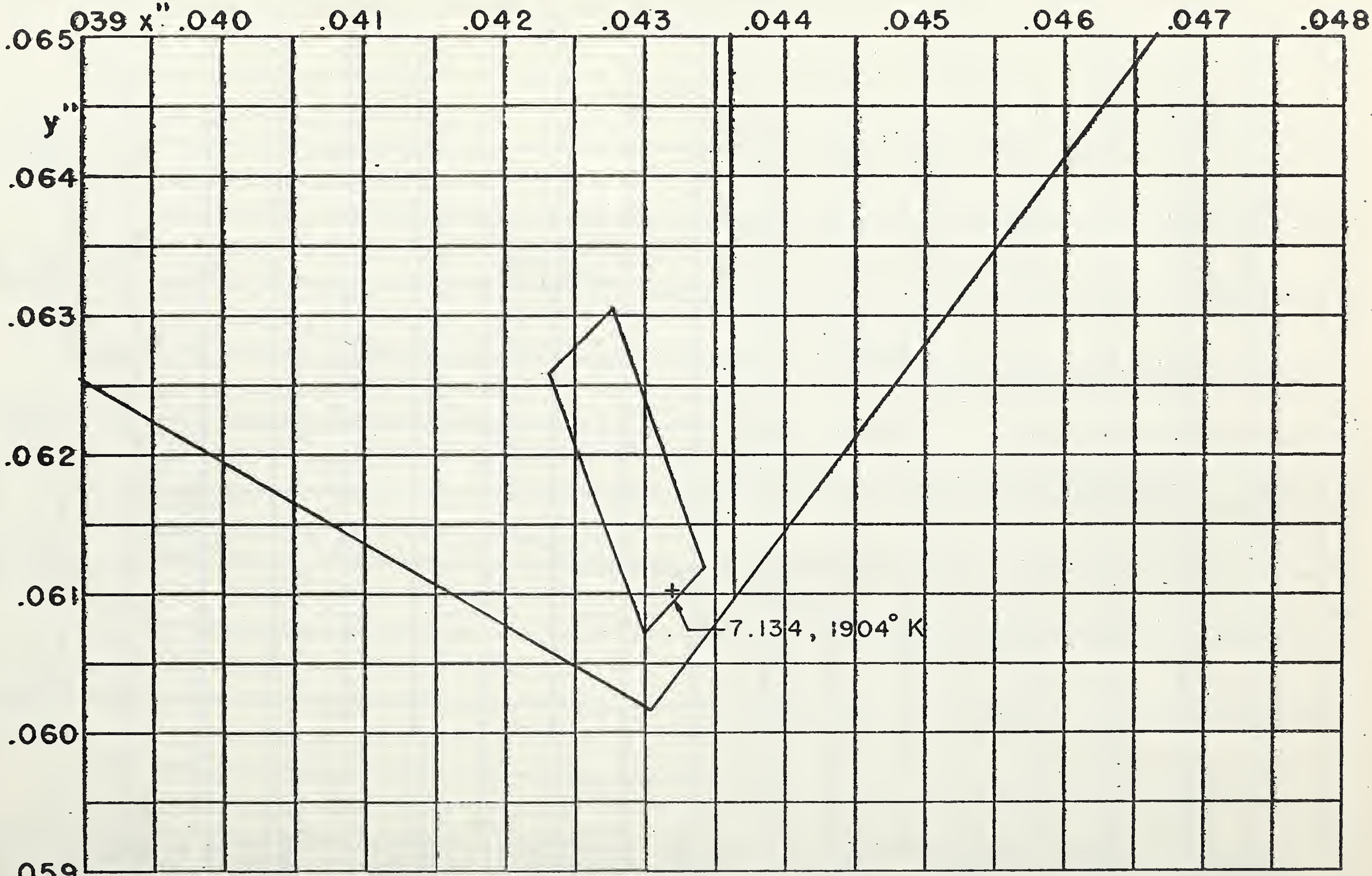

Figure 5. Tolerances for Green Filters. RUCS transformation of Figure 4 in more nearly uniformly-spaced chromaticities.

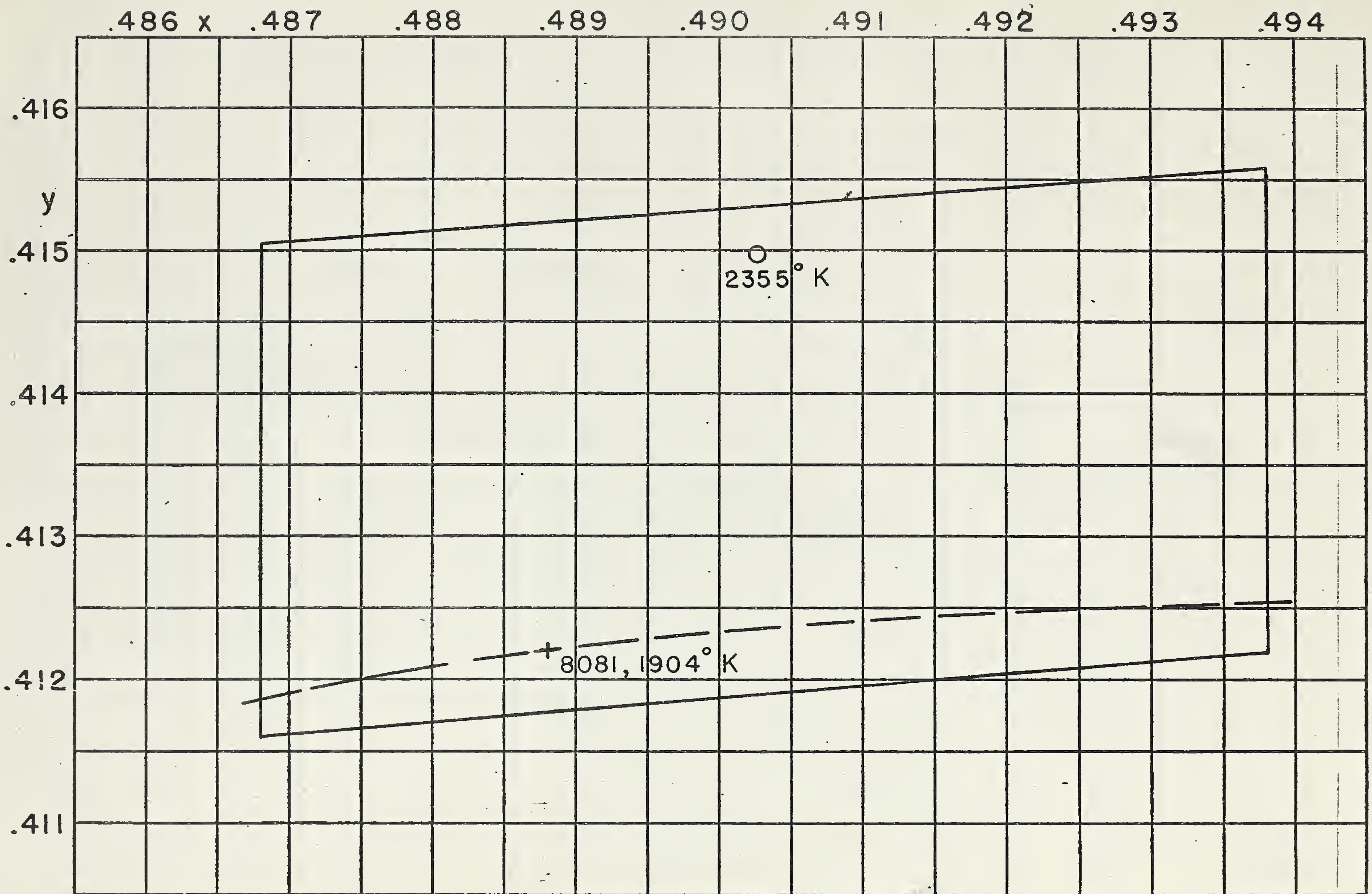

Figure 6. Tolerances for Lunar Filters. C.I.E. chromaticity diagram showing tolerances proposed in Table III for "white" filters.

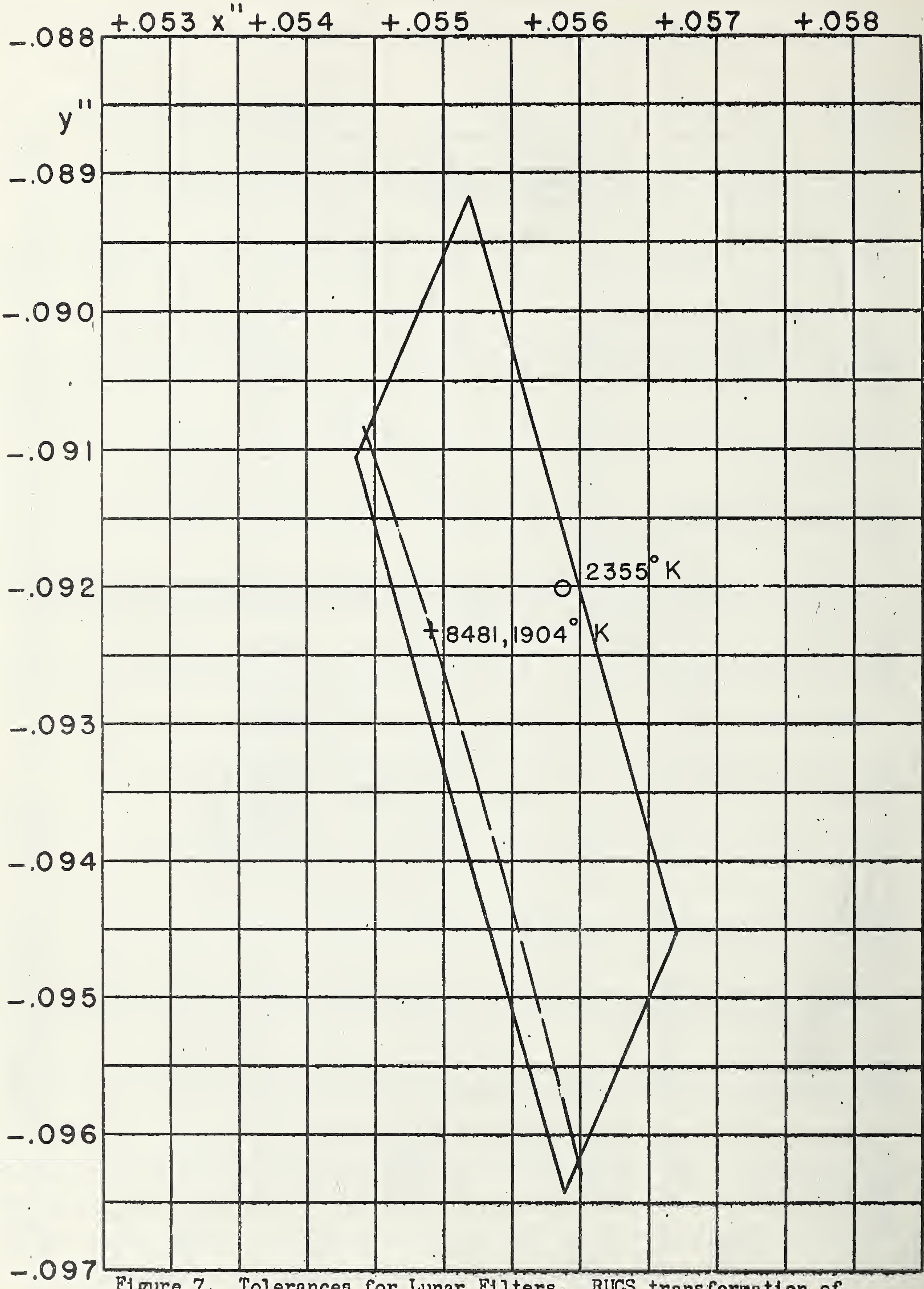

Figure 7. Tolerances for Lunar Filters. RUCS transformation of Figure 6 in more nearly uniformly-spaced chromaticities.

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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Circuit Standards. High Frequency Electrical Standards. Microwave Circuit Standards. Electronic Calibration Center.

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